Interventional Neuroradiology 5: 139-144, 1999

Pressure Measurements across Vascular Stenoses

Practice and Pitfalls

S.G. IMBESI, C.W. KERBER*

Department of Radiology, Hospital of the University of Pennsylvania; Philadelphia, Pennsylvania USA
Department of Radiology, University of California, San Diego Medical Center; San Diego, California USA

Key words: flow dynamics, vascular pressure gradients, carotid stenosis

Summary

We describe and analyze pressure measurements across vascular stenoses in an atherosclerotic human carotid bulb replica using catheters of different diameters.

Replicas of an atherosclerotic human carotid bulb were created using the lost wax technique, and were placed in a circuit of pulsating non-newtonian fluid. Flows were adjusted to replicate human physiologic flow profiles. Common carotid artery total flow volume of 600 milliliters/minute was studied. A pressure recording device was calibrated; data were received from catheters placed longitudinally in the common carotid artery and internal carotid artery. The internal carotid artery pressures were obtained both through the stenosis as is usually performed in the angiography suite and through the vessel side-wall beyond the stenosis as a control. Internal carotid artery flow volumes were also measured with and without the catheter through the stenosis. Multiple pressure recordings and volume measurements were obtained in the replica using 7 French, 5 French, and 2.5 French catheters.

Measurements of the replica showed a 58% diameter stenosis and an 89% area stenosis of the carotid bulb. All longitudinal pressure measurements in the common carotid artery agreed with control values regardless of the diameter of the catheter used. Pressure measurements were also in agreement with control values in the internal carotid artery using the 2.5 French catheter. However, when larger diameter catheters were employed, pressures measured with the catheter through the stenosis fell when compared to control values. Additionally, internal carotid artery flow volumes were also decreased when the larger diameter catheters were placed across the stenosis.

Large diameter catheters when placed across vascular stenoses may cause an occlusive or near-occlusive state and artifactually increase the measured transstenotic vascular pressure gradient as well as decrease forward vascular flow.

Introduction

Pressure gradients across vascular stenoses are generally measured through end-hole catheters to assess the degree of stenosis and improvement of lumen diameter following angioplasty [1-8]. However, the effect of the catheter itself on the pressure measurements has not been extensively studied. We recently obtained a fresh cadaver having a stenotic carotid bulb, made accurate castings and reproductions of that carotid arterial system, and studied the pressure gradients and flows in the system with catheters of different sizes within the vessel replica. The use of silicone vascular replicas allows for direct in vitro measurement and determination of accuracy with control values. We now report the results of those experiments.

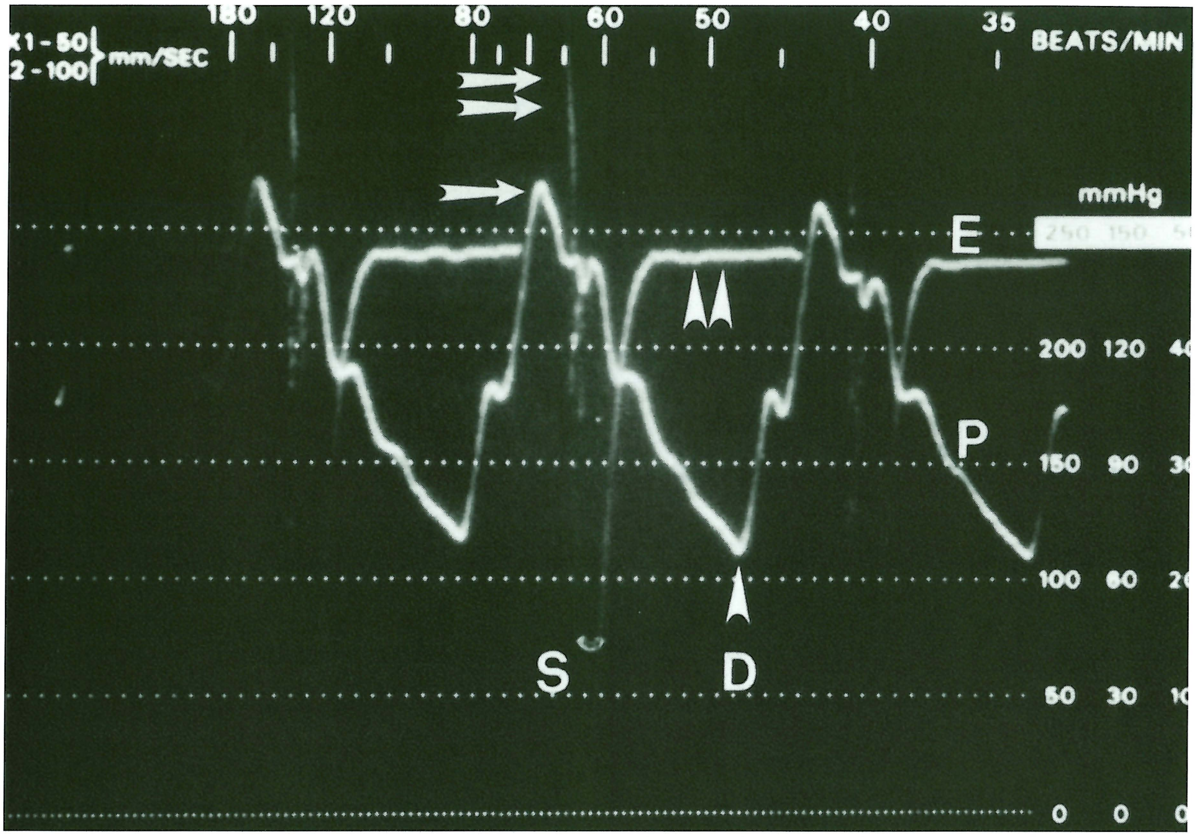

Figure 1 Recorded pressure tracings synchronized to an electrocardiograph demonstrate increased pressure (single arrow) during systole (double arrows) and decreased pressure (single arrowhead) during diastole (double arrowheads). E = Electrocardiograph tracing, P = Pressure tracing, S = Systole, and D = Diastole.

Material and Methods

We created a cast of an atherosclerotic stenotic carotid bulb from a fresh human cadaver using the lost wax technique [9,10]. Multiple clear elastic silicone replicas made from the original cast were placed in a circuit of pulsatile non-newtonian fluid [11,12].

A blood pump (model 1421 Harvard apparatus, Holliston, Massachusetts) cycling at one pulse per second provided fluid flow. Flows were adjusted to replicate human physiologic flow profiles with a Square Wave Electromagnetic Flowmeter (Carolina Medical Electronics, Inc., King, North Carolina).

Common carotid artery total flow volume of 600 milliliters/minute (ml/min) was utilized. The proximal internal carotid artery stenosis resulted in 50% of total flow passing into the internal carotid artery and 50% of the total flow into the external carotid artery. We calibrated a pressure recording device (Tektronix #414 Dual Pressure Opt. 21, Beaverton, Oregon) in the flowing fluid and synchronized it to the blood pump via an electrocardiograph monitor (Tektronix) to show peak systole (figure 1).

2.5 French (F), 5 F, and 7 F single end-hole straight catheters were attached to the pressure recorder and placed longitudinally within the replica, as would be done in a patient. Pressure measurements were obtained in the common carotid artery and internal carotid artery following passage of the catheter beyond the carotid bulb stenosis. Control pressure measurements were also taken at the same locations following insertion of the catheter through the side-wall of the vessel, that is without the catheter passing through the carotid bulb stenosis (figure 2). Internal carotid artery flow volumes were also measured with a graduated cylinder over time prior to and during catheter placement through the stenosis.

Table 1 **Ratios of catheter area to artery area**

		Artery CCA	Stenosis
	2.5 F	1.20%	11.6%
Catheter	5 F	5.02%	48.4%
	7 F	10.4%	100%

CCA = Common carotid artery; Stenosis = Narrowed carotid bulb

Table 2 **Longitudinal pressures: peak systole / peak diastole**

		Catheter 2.5 F	5 F	7 F
	CCA	49/37	56/35	56/33
	CCAc	51/39	58/36	58/35
Vessel	ICA	41/33	37/27	28/23
	ICAc	43/34	50/30	51/31

CCA = Common carotid artery; ICA = Internal carotid artery; c = control;
Pressure measured in centimeters of water (cm H_2O)

Table 3 **Calculated trans-stenosis systolic pressure gradients**

		Catheter 2.5 F	5 F	7 F
Pressure gradient	Measured	8	19	28
	Actual	8	8	7

Pressure measured in cm H_2O

Results

Measurements

Measurements of the vascular cast are as follows: The common carotid artery measured 7.14 mm diameter (40.0 mm^2 cross-sectional area), the narrowest portion of the carotid bulb 2.30 mm diameter (4.15 mm^2 area), and the internal carotid artery 5.50 mm diameter (23.8 mm^2 area).

These values equate to a 58% diameter stenosis of the carotid bulb by NASCET criteria using the internal carotid artery as a reference and an 89% area stenosis of the carotid bulb using the common carotid artery as a reference.

The arterial replicas reproduced the original dimensions of the cadaver specimen to within 1%. Measurements of the tips of the 2.5 F, 5 F, and 7 F catheters are 0.78 mm diameter (0.48 mm^2 area), 1.60 mm diameter (2.01 mm^2 area), and 2.30 mm diameter (4.15 mm^2 area), respectively. The ratios of catheter area to vessel area are shown in table 1.

Pressures

Longitudinal pressure recordings throughout the cardiac cycle synchronized to peak systole at flow volumes of 600 ml/min yielded the results in table 2. From these data measured systolic pressure gradients and true systolic pressure gradients (using the control values) were calculated and are shown in table 3. Systolic pressure gradient values are felt to represent the most accurate determinate of degree of vascular stenosis [13].

Pressure measurements in the common carotid artery showed essentially no change with the control values. There was similar agreement in the internal carotid artery with the small 2.5 F microcatheter. However, when the larger catheters were placed through the stenosis there was a significant decrease in the measured internal carotid artery pressures compared to the control values, and hence an increase in the measured transstenotic pressure gradient.

Flows

Prior to catheter placement through the stenosis, flow in the internal carotid artery was 300 ml/min. With the small 2.5 F microcatheter through the stenosis, flow in the internal carotid artery only minimally decreased to 290 ml/min.

When the larger 5 F and 7 F catheters were inserted through the stenosis, flow marked decreased to 185 ml/min, and 7 ml/min, respectively.

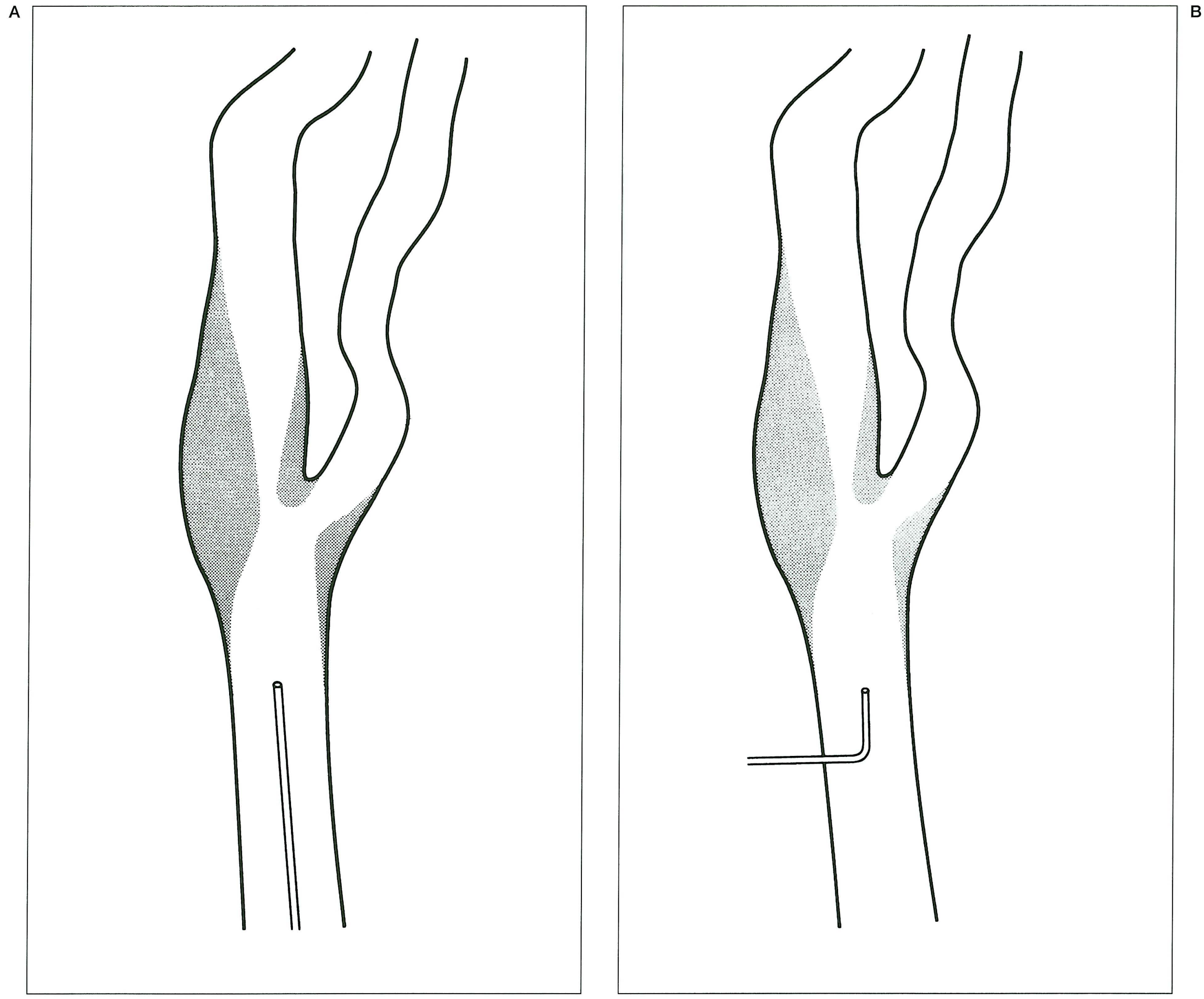

Figure 2

Discussion

Pressure gradients across vascular stenoses are currently utilized to assess the severity of luminal narrowing as well as the degree of success following angioplasty [1-8].

Prior publications have suggested that further luminal compromise by placement of an end-hole catheter through the stenosis may alter the validity of these measurements [14-18].

In addition, Serruys et al described overestimation of the transstenotic pressure gradient by approximating vascular flow and stenosis geometry from theoretical mathematical models [19]. However, elastic silicone vascular replicas made from human cadavers allow us to directly measure the vascular pressures in vitro and compare these results with control values.

As expected, pressures measured in the common carotid artery agreed with control values regardless of catheter diameter, confirming the control value validity.

Measuring with a microcatheter placed through the narrowed carotid bulb, which only slightly increases the degree of vascular stenosis, gives values in the internal carotid artery that agree with control values. Internal carotid artery total flow was essentially unchanged when the microcatheter was pushed through the stenosis. The catheter area to stenosis area

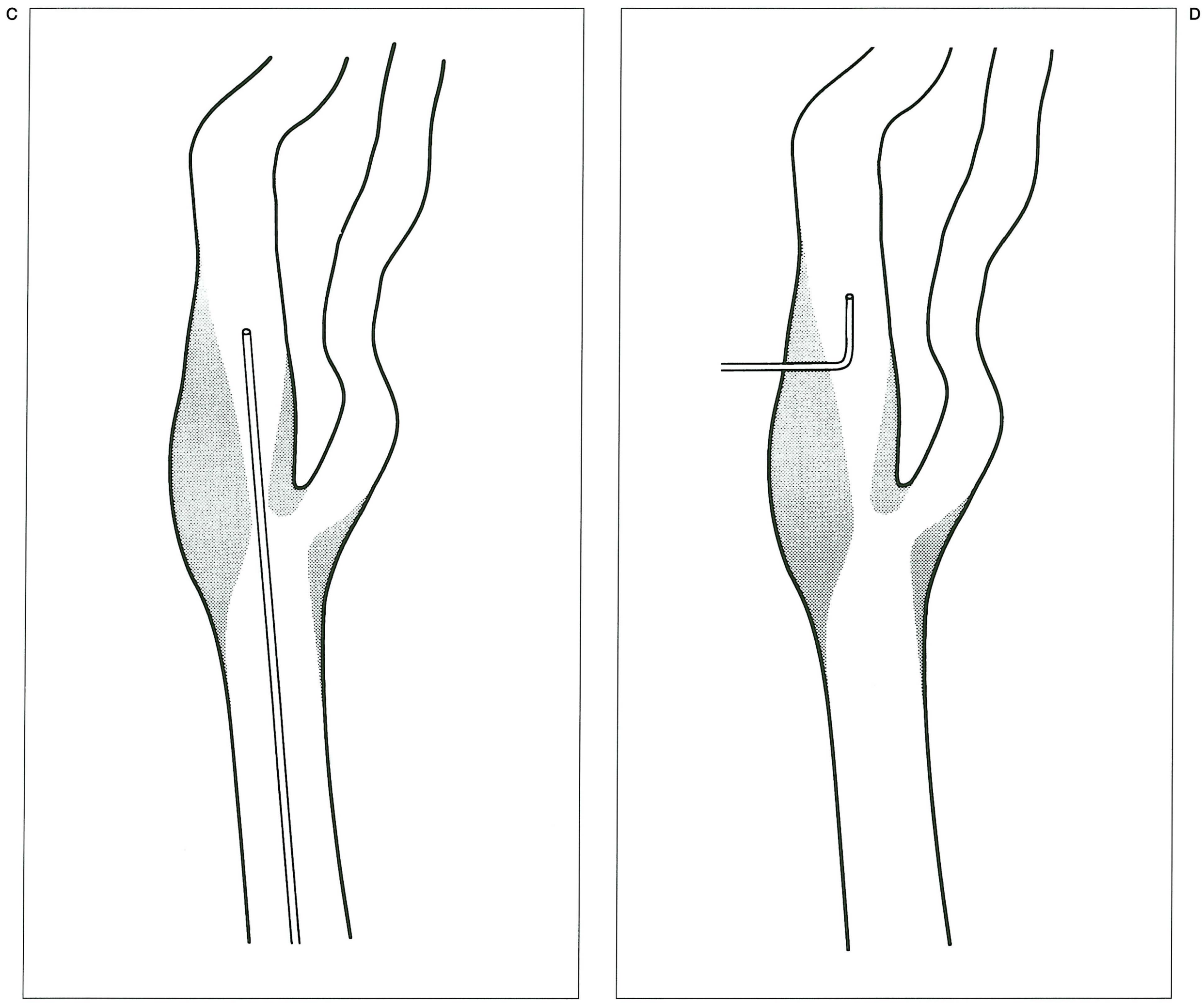

Figure 2 Catheter with the tip placed longitudinally in the common carotid artery (A) with control (B) and catheter with the tip placed longitudinally in the internal carotid artery (C) with control (D).

ratio was only 11.5%. However, when the 5 F catheter was placed through the narrowed carotid bulb, the degree of vascular stenosis increased, and internal carotid artery flow decreased.

The ratio of catheter area to stenosis area was 48.4%. This led to a decreased measured pressure in the internal carotid artery (compared to the control) and an overestimation of the measured transstenotic systolic pressure gradient. Producing an occlusive state with the 7 F catheter, the catheter area to stenosis area ratio was 100%, further exaggerated these observations.

Therefore, when using end-hole catheters for transstenotic pressure gradient measurements, the smaller diameter catheters, in particular the use of microcatheters, will yield more accurate results. The advent of carotid angioplasty and stenting knowledge of these principals will result in more accurate patient assessment and evaluation of therapy success.

Acknowledgements

We gratefully acknowledge Mr. Dennis J. English and Mr. Ronald C. Thomas for their invaluable assistance in preparing the manuscript.

References

1 Nahman NS jr, Maniam P et Al: Renal artery pressure gradients in patients with angiographic evidence of atherosclerotic renal artery stenosis. Am J Kidney Dis 24(4): 695-699, 1994.
2 Breslau PJ, Jorning PJ, Greep JM: Assessment of aortoiliac disease using haemodynamic measures. Arch Surg 120(9): 1050-1052, 1985.
3 Young DF, Cholvin NR, Roth AC: Pressure drop across artificially induced stenoses in the femoral arteries of dogs. Circ Res 36(6): 735-743, 1975.
4 Wijns W, Serruys PW et Al: Quantitative angiography of the left anterior descending coronary artery: correlations with pressure gradient and results of exercise thallium scintigraphy. Circulation 71(2): 273-279, 1985.
5 Tetteroo E, Haaring C et Al: Intraarterial pressure gradients after randomized angioplasty or stenting of iliac artery lesions. Dutch Iliac Stent Trial Study Group. Cardiovasc Intervent Radiol 19(6): 411-417, 1996.
6 Pijls NH, van Son JA et Al: Experimental basis of determining maximum coronary, myocardial, and collateral blood flow by pressure measurements for assessing functional stenosis severity before and after percutaneous transluminal coronary angioplasty. Circulation 87(4): 1354-1367, 1993.
7 Kimball BP, Bui S et Al: Residual coronary stenoses and calculated transstenotic gradients after intravenous streptokinase versus tissue plasminogen activator. Am Heart J 123(1): 7-14, 1992.
8 Hahnloser P, Glinz W: Relationship between the pressure gradient and the decrease of blood pressure in acute experimental stenosis of the mesenteric arteries. Helv Chir Acta 40(1): 279-286, 1973.
9 Kerber CW, Heilman CB, Zanetti PH: Transparent elastic arterial models. I. A brief technical note. Biorheology 26(6): 1041-1049, 1989.
10 Liepsch D, Zimmer R: A method for the preparation of true-to-scale inflexible and natural elastic human arteries. Biomed Techn 23(10): 227-230, 1978.
11 Mann DE, Tarbell JM: Flow of non-Newtonian blood analog fluids in rigid curved and straight artery models. Biorheology 27(5): 711-733, 1990.
12 Liepsch D, Morabec ST: Pulsatile flow of non-Newtonian fluid in distensible models of human arteries. Biorheology 21(4): 571-586, 1984.
13 Archie JP jr: Analysis and comparison of pressure gradients and ratios for predicting iliac stenosis. Ann Vasc Surg 8(3): 271-280, 1994.
14 Leiboff R, Bren G et Al: Determinants of transstenotic gradients observed during angioplasty: an experimental model. Am J Cardiol 52: 1311-1317, 1983.
15 Ganz P, Harrington DP et Al: Phasic pressure gradients across coronary and renal artery stenoses in humans. Am Heart J 106(6): 1399-1406, 1983.
16 Sievert H, Kaltenbach M: Measuring the intracoronary pressure gradient - value and methodologic limitations. Z Kardiol 76(6): 323-325, 1987.
17 Abildgaard A, Klow N, Endresen K: Evaluation of a pressure recording guidewire in patients with coronary arterial disease. Cathet and Cardiovasc Diag 41: 200-207, 1997.
18 DeBruyne B, Sys S, Heyndrickx GR: Percutaneous transluminal coronary angioplasty catheters verses fluid filled pressure monitoring guidewires for coronary pressure measurements and correlation with quantitative coronary angiography. Am J Cardiol 72: 1101-1106, 1993.
19 Serruys PW, Wijns W et Al: Values and limitations of transstenotic pressure gradients measured during percutaneous coronary angioplasty. Herz 10(6): 337-342, 1985.

Steven G. Imbesi, M.D.
Assistant Professor of Radiology
Department of Radiology
Hospital of the University of Pennsylvania
3400 Spruce St., Gd. Fl. Founder's Bldg.
Philadelphia, Pennsylvania 19104
USA